


Assembly history of subhalo populations in galactic and cluster sized dark haloes

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ABSTRACT

We make use of two suits of ultra high resolution N-body simulations of individual dark matter haloes from the Phoenix and the Aquarius Projects to investigate systematics of assembly history of subhaloes in dark matter haloes differing by a factor of 1000 in the halo mass. We have found that *real* progenitors which built up present day subhalo population are relatively more abundant for high mass haloes, in contrast to previous studies claiming a universal form independent of the host halo mass. That is mainly because of repeated counting of the ‘re-accreted’ (progenitors passed through and were later re-accreted to the host more than once) and inclusion of the ‘ejected’ progenitor population (progenitors were accreted to the host in the past but no longer members at present day) in previous studies. The typical accretion time for all progenitors vary strongly with the host halo mass, which is typical about $z \sim 5$ for the galactic Aquarius and about $z \sim 3$ for the cluster sized Phoenix haloes. Once these progenitors start to orbit their parent haloes, they rapidly lose their original mass but not their identifiers, more than 55 (50) percent of them survive to present day for the Phoenix (Aquarius) haloes. At given redshift, survival fraction of the accreted subhalo is independent of the parent halo mass, whilst the mass-loss of the subhalo is more efficient in high mass haloes. These systematics results in similarity and difference in the subhalo population in dark matter haloes of different masses at present day.

Key words: cosmology: dark matter – methods: numerical

1 INTRODUCTION

In the standard Λ CDM cosmology, dark matter subhaloes are consequence of hierarchical clustering of dark matter haloes. During the hierarchical process, the accreted dark matter halo often survive as self-bound subhalo orbiting its host (e.g. Tormen, Diaferio & Syer 1998; Ghigna et al. 2000; Springel et al. 2001; De Lucia et al. 2004; Gao et al. 2004, 2012; Diemand, Kuhlen & Madau 2007; Springel et al. 2008). In observations, subhaloes have been detected with gravitation lensing (Vegetti et al. 2012; Li et al. 2014) in recent years.

Thanks to great advance in high resolution cosmological simulations, properties of subhaloes have been extensively investigated in recent years. Regardless of a variety of different definitions of subhalo in cosmological simulations, numerical studies tend to agree on a number of basic properties of the subhalo population in Λ CDM haloes. 1) Because of efficient tidal stripping of the subhalo population, in particularly in inner region of its host halo, the subhalo population is a biased tracer of dark matter distribution of its host. The distribution of subhaloes is substantially less concen-

trated than that of the underlying dark matter (e.g. Ghigna et al. 2000; Gao et al. 2004; Nagai & Kravtsov 2005). With ultra high resolution of numerical simulation of the Phoenix and the Aquarius projects, Gao et al. (2012) shows that the radial distribution of subhalo is independent on the subhalo and the host halo mass. 2) The mass function of subhaloes follow a power law relation $dN(>M_{sub})/dM_{sub} \propto M_{sub}^\alpha$ (Boylan-Kolchin et al. 2009; Gao et al. 2011) with a slope α varying from 1.9 to 2, depending on the employed subhalo finder (Onions et al. 2013). The subhalo mass function is found to be correlated with the host halo mass, with the more massive halo tends to contain more abundant subhaloes (Gao et al. 2004, 2011; Ishiyama et al. 2013). On average, the amplitude of the subhalo mass of rich cluster sized haloes is about 40 percent higher than that of galactic haloes (Gao et al. 2012). The subhalo mass function also correlates with the host halo properties, for instance halo concentration and formation time (Gao et al. 2004, 2011; Contini, De Lucia & Borgani 2012). Convincing and explicit explanations of the host halo mass and properties dependence of the subhalo mass function still lack. In light of numerical works, properties of the subhalo population have also been extensively studied with semi-analytic models (e.g. Taylor & Babul

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2005; Zentner et al. 2005; Giocoli, Tormen & van den Bosch 2008; Yang et al. 2012; Jiang & van den Bosch 2014).

Most previous studies on the subject have focused on investigating the subhalo population at redshift $z = 0$. In this study, we complement those by investigating the evolution of subhalo population. More specifically, we will study systematics in the assembly of subhaloes across cosmic time and in haloes of different masses. To this end, we make use of two ultra high resolution of N -body simulations of individual dark matter haloes from the Phoenix and the Aquarius project. The simulated dark matter haloes in the Phoenix and Aquarius project differ by a factor of 1000 in the halo mass, thus provide an ideal sample to study the assembly of subhaloes in the dark matters halo with different masses. It is worthwhile mentioning that the Phoenix and the Aquarius simulations have very similar effective mass and force resolution in terms of the simulated particle number. This allows us to facilitate easy comparison between the two simulation sets.

Our paper is organized as follows. In Section 2, we briefly describe the numerical simulations used in this study. In Section 3 we present result of the progenitor population of the Phoenix and the Aquarius haloes before accretion. We contrast results for the evolution of the subhalo population in the Phoenix and Aquarius simulations in Section 4. Section 5 summarize our main findings.

2 SIMULATION

Numerical simulations used in this study comprise two sets of ultra high resolution re-simulation of individual dark matter haloes from the Phoenix (Gao et al. 2012) and the Aquarius Projects (Springel et al. 2008) of the Virgo consortium. In terms of the numerical resolution, the two projects are respective representation of the current state-of-art N -body simulations of rich cluster and Milky way sized dark matter haloes. For objective of numerical convergence study, both the Phoenix and the Aquarius suits have run simulations with various resolutions. In this study we have adopted level-2 resolution of each simulation sets. At the level-2 resolution, each of 9 Phoenix clusters and 6 Aquarius galactic haloes contains about 10^8 particles within their virial radius R_{200} . Here R_{200} is defined as a radii at which the enclosed density is 200 times of critical density of the Universe. Hence both simulation suits indeed have identical effective mass and force resolution. This allows us to facilitate easy comparison of results between two simulation sets. Note, we adopt 7 Phoenix clusters which there is no ambiguity in constructing their main branch merger trees.

The Phoenix cluster and the Aquarius galaxy sample were selected for resimulation from the Millennium simulation (Springel et al. 2005). The Millennium simulation assume Cosmological parameters consistent with first year WMAP data were adopted, $\Omega_m = 0.25$, $\Omega_b = 0.045$, $\Omega_\Lambda = 0.75$, $h = 0.73$, $\sigma_8 = 0.9$, $n = 1$. These parameters deviate from the latest CMB result, however the small offset has no consequence for the topic addressed here. We refer readers to Gao et al. (2012) and Springel et al. (2008) for details of the Phoenix and the Aquarius simulation suits.

The dark matter haloes in our simulations are identified with standard friends-of-friends group algorithm with a linking length 0.2 times inter-particles separation (Davis et al. 1985). Based upon FOF group catalog, we identify locally over-dense and self-bound subhaloes with SUBFIND (Springel, Yoshida & White 2001). The subhalo catalog is used to construct merger trees tracking subhaloes between snapshots (e.g. Boly-choin et al. 2009).

3 THE UN-EVOLVED SUBHALO MASS FUNCTION

The un-evolved subhalo mass function describes the mass spectrum of the building-up progenitors over the entire life time of a halo assembly. It is therefore interesting to investigate whether the un-evolved subhalo population in the cluster and the galaxy sized halo is different. Namely whether the different subhalo abundance between the cluster sized and galactic haloes seen today is set at the first place. Previous studies on the subject claimed that the un-evolved subhalo mass function follows an universal function and is independent of halo mass (see Giocoli, Tormen & van den Bosch (2008); Li & Mo (2009), van den Bosch, Tormen & Giocoli (2005)). This is surprising because the standard Λ CDM power spectrum is not scale free, it is not obvious that the un-evolved subhalo mass function should be identical in haloes of different scales. We re-examine this independently in this work as follows.

We first construct the halo main branch for each individual halo. Starting from the final halo at $z = 0$, we trace its most massive progenitor in the adjacent snapshot at earlier epoch. The procedure is repeated until the simulation lost its resolution to identify a halo (32 dark matter particles for a FOF halo by our definition). Next we add a halo as a progenitor candidate if it is accreted into R_{200} of its main branch at later time. The accretion time for a subhalo is defined at the time when it has peak virial mass M_{200} in its growth history. Correspondingly, its mass at accretion time is defined as the mass of the progenitor halo. The definition here is used because the stellar mass of satellite galaxies are more tightly related to the peak M_{200} (Guo et al. 2010; Watson & Conroy 2013; Boylan-Kolchin et al. 2009). Note there are a couple of definitions on accretion time of a subhalo. For example, some studies (Gao et al. 2004; Li & Mo 2009) define the accretion time when an individual halo becomes a subhalo of a FOF halo. Some studies (Giocoli, Tormen & van den Bosch 2008) adopt the time when an individual halo pass virial radius of its host halo.

The merging history of dark haloes are generally quite complicated (Kravtsov et al. 2004). We need to consider two special cases below. 1) 'Ejected' halo: namely a halo was only a temporal progenitor at earlier time but passed through its host and became an isolated haloes in its later evolution. The ejected progenitor population have been investigated by (Ludlow et al. 2009; Wang, Mo & Jing 2009; Li et al. 2013). As these ejected progenitors have no influence on the final subhalo population at present day, we remove them from our progenitor catalog. 2) 'Re-accreted' halo: a 're-accreted' progenitor refer to a halo passing through the main branch more than once in the past, but either is completely disrupted or retains as a subhalo of the host halo lastly. In this case, we only register it at the first infall. Lastly, we also add haloes merged with other progenitor rather than the main branch. For these progenitors, we apply for the same procedure above for the progenitors of the main branch to make sure they are members of the final halo.

Our definition of the un-evolved subhalo mass function is somewhat different from Giocoli, Tormen & van den Bosch (2008); Giocoli et al. (2010) and Li & Mo (2009). In these works, a halo is called a progenitor if it becomes a member of the FOF group (Li & Mo 2009) of the main branch haloes or pass through the virial radius (Giocoli, Tormen & van den Bosch 2008; Giocoli et al. 2010). Whilst we consider a halo to be a progenitor only if it is accreted into R_{200} of the host.

There are also significant differences in the detailed tracking procedure. In Giocoli, Tormen & van den Bosch (2008), the au-

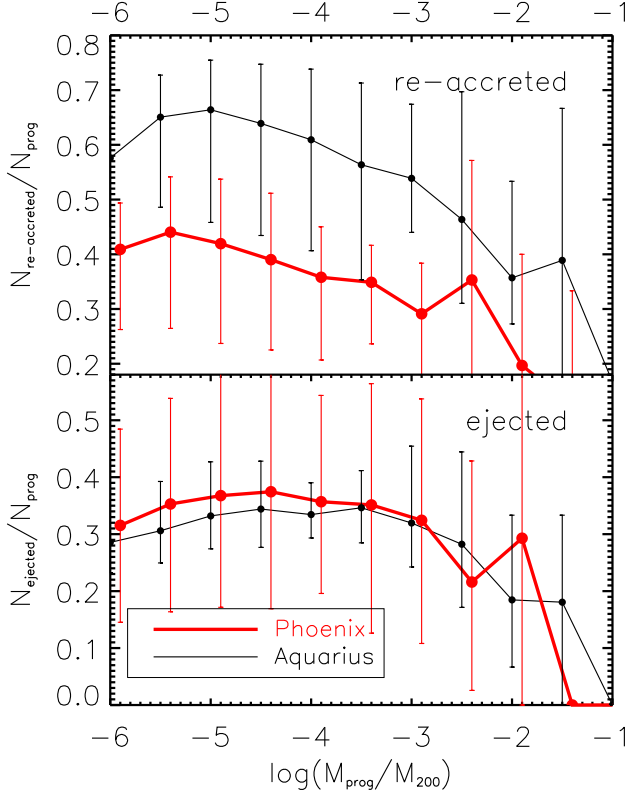


Figure 1. The averaged fraction of the ‘re-accreted’ progenitor (top panel) and the ‘ejected’ halos (bottom panel) compared to the total number of real progenitors as a function of progenitor halo mass. The results of 7 Phoenix halos are shown as thick red lines. The results of 6 Aquarius halos are shown as thin black lines. The error bars on selected points show full scatters of our samples.

thors only considered progenitors merged with main branch but neglected the subhalo population merged with subbranch progenitors. This of course excludes a significant progenitor population. Li & Mo (2009) improved this by considering all mergers as we did. But we differ in definition of the progenitor masses, also in treating the ‘re-accreted’ and the ‘ejected’ halos. Since an ‘re-accreted’ progenitor is basically the same object during multiple mergers with its host halo and contains the same central galaxy, it is more reasonable to consider it as a single progenitor. While in Li & Mo (2009), it was repeatedly counted as new individual progenitors during each merging events. In fact, as shown below both the ‘re-accreted’ and the ‘ejected’ halos are substantial populations of the progenitor as a whole, which greatly affect the un-evolved subhalo mass function.

In the top panel of Figure 1, we plot the averaged fraction of the ‘re-accreted’ progenitor of the 7 Phoenix and the 6 Aquarius haloes as a function of the progenitor mass (normalized to the host halo mass at $z = 0$) by solid lines. Only for the massive progenitors with mass greater than $1/100$ of their parent, the fraction of the ‘re-accreted’ progenitors is small for both the Phoenix and the Aquarius haloes. However, for progenitors less massive than the ratio, the ‘re-accreted’ progenitor is a significant population of the progenitor as a whole. About 40 percent of progenitors are ‘re-accreted’ pro-

genitors in Phoenix clusters. Up to 60 percent progenitors of Aquarius haloes are ‘re-accreted’ progenitors. The ‘re-accreted’ fraction decreases with increasing progenitor mass. These ‘re-accreted’ progenitors have been repeatedly counted in un-evolved subhalo mass function of Giocoli, Tormen & van den Bosch (2008) and Li & Mo (2009).

The bottom panel of figure 1 shows the averaged ratio between the number of the ‘ejected’ halos and real progenitors as a function of the progenitor mass. The ‘ejected’ fraction is about 30% – 35% and seems independent on progenitor and host halo mass.

In Figure 2 we plot our own un-evolved subhalo mass function for the Phoenix and the Aquarius simulation suits. In the plot, the median value of the cumulative un-evolved subhalo mass function of the 7 Phoenix and the 6 Aquarius haloes are shown as red and black solid lines, respectively. The cumulative mass functions are multiplied by M_{prog}/M_{halo} in order to remove the dominant mass dependence and make the differences between curves more apparent. Clearly the un-evolved subhalo mass function depends on the halo mass, with the cluster sized Phoenix having 20% more progenitors than that of Aquarius galactic haloes. The un-evolved mass functions are well fitted by:

$$f(N > \mu \equiv \frac{M_{prog}}{M_{200}}) = \left(\frac{\mu}{a}\right)^b \exp\left[-\left(\frac{\mu}{c}\right)^d\right] \quad (1)$$

For Phoenix haloes, the parameters are $a = 0.125$, $b = -0.95$, $c = 0.1$, $d = 12$. For Aquarius haloes, the parameters are $a = 0.105$, $b = -0.95$, $c = 0.09$, $d = 1.72$.

Our result hence is inconsistent with Giocoli, Tormen & van den Bosch (2008) and Li & Mo (2009), who claimed that an universal form for the un-evolved subhalo mass function independent of the host halo mass. The reason for the discrepancy has been discussed above when we elucidate differences in the definitions of the un-evolved subhalo population among ours. It is worthwhile mentioning that when we use the same definition of the un-evolved subhalo population as Giocoli, Tormen & van den Bosch (2008); Li & Mo (2009), our own results agree quite well with Giocoli, Tormen & van den Bosch (2008) and Li & Mo (2009). Hence the discrepancy shown here is entirely because of the different definitions of the un-evolved subhalo population. For comparison, we over-plot the fit of all order un-evolved subhalo mass function of Li & Mo (2009) as a blue dotted curve. The amplitude is about 20% to 50% larger than ours. This is expected for three reasons. Firstly, Li & Mo (2009) based their work on FOF haloes, whereas ours is based upon spherical over-densities. Secondly ‘re-accreted’ progenitors were counted multiple times by Li & Mo (2009), and ‘ejected’ haloes were included by Li & Mo (2009), these increase the amplitude of the un-evolved subhalo mass function. Third, we use peak M_{200} as infall mass, which is larger than that defined in Li & Mo (2009).

For easy reference, we over-plot the median of the subhalo mass function of the Phoenix and Aquarius haloes as black and red dashed lines in the same figure, respectively. The difference in the amplitude of the subhalo mass function between the Phoenix and the Aquarius is about 40 percent, larger than the difference seen in the un-evolved subhalo mass function. This suggests that subsequent evolution of the subhalo population should also be important to account for the parent halo mass dependent subhalo mass function abundance as will be analyzed below.

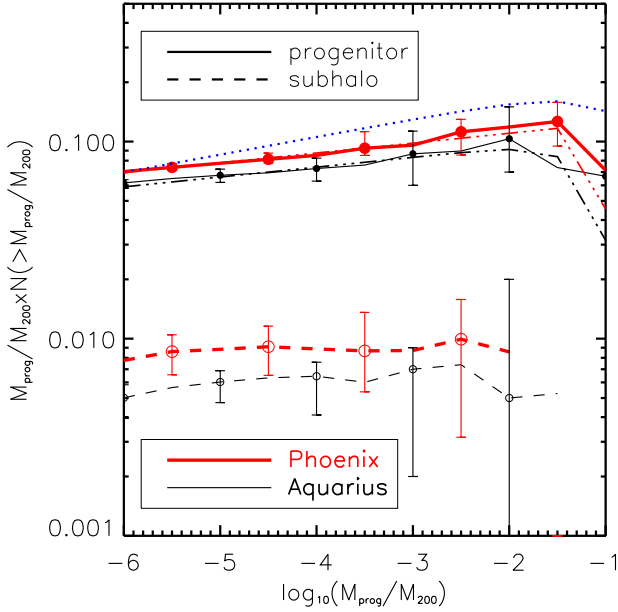


Figure 2. Cumulative un-evolved (solid lines) and present subhalo mass function (dashed lines) of cluster sized Phoenix (red, thick) and galactic Aquarius (black, thin) haloes. The y axis has been multiplied by the normalized mass in order to expand the dynamic range. The lines show the median subhalo mass function for samples of 7 haloes in the Phoenix and the 6 haloes in the Aquarius simulation suits. The error bars show whole scatter about the median. The dash-dotted lines show our fits to our simulations. The un-evolved subhalo mass function of Li & Mo (2009) is shown as blue dotted lines.

4 THE ASSEMBLY HISTORY OF SUBHALO POPULATION

Above we studied the progenitor population before accretion. In this section, we will investigate the evolution of the progenitors after they were accreted into their parent haloes.

4.1 Accretion time distribution of progenitors

In top panel of Fig. 3, we show the accretion time distribution of all progenitors as a function of the progenitor mass (upper axis) for the Phoenix and Aquarius haloes. Hereafter we will use the normalized mass for the progenitor and the subhalo rather than their actual masses in order to take out the host halo mass dependence. The median accretion time of all progenitors in the entire assembly history of 7 phoenix and 6 Aquarius haloes is shown as the red and black solid lines, respectively. Error bars display full scatter of the accretion time distribution for the Phoenix and Aquarius haloes. Here we define the accretion time as the redshift when a progenitor reaches its peak M_{200} . Clearly, there is a strong relation between the accretion time and the progenitor mass for both the Phoenix and the Aquarius haloes, with less massive progenitors accreted earlier than their more massive counterparts. Most Progenitors of the Aquarius haloes are typically accreted before redshift 5, while it is about $z \sim 3$ for the Phoenix haloes.

The offset in the accretion time distribution between the Phoenix and the Aquarius haloes may reflect the fact that cluster haloes are assembled later.

The bottom panel of Fig. 3 show the accretion time distri-

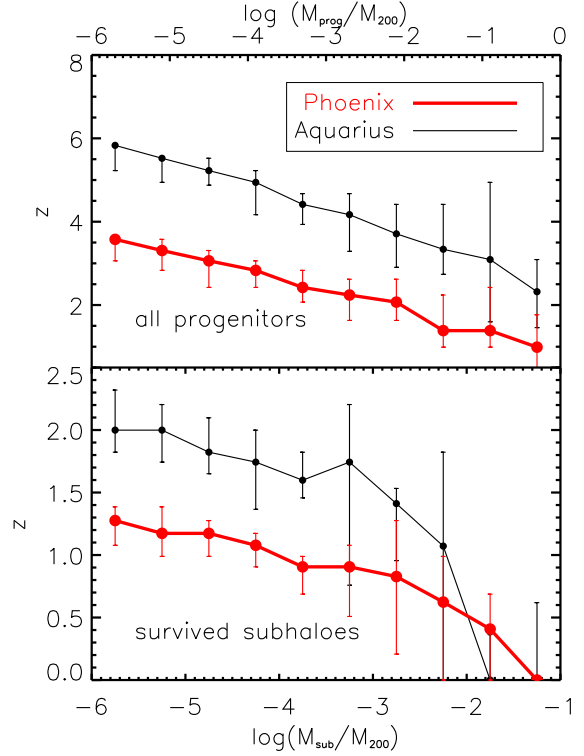


Figure 3. Accretion time distribution. The top panel show the median accretion time distribution of all progenitors of the Phoenix and the Aquarius haloes as a function of the progenitor mass (upper axis). The bottom panel show the median accretion time of the survived subhaloes as a function of the subhalo mass. The median values of the Phoenix and the Aquarius haloes are plotted. Different colours are used to distinguish the different simulation sets as indicated in the legend. The error bars show the full scatter about the median.

bution of the present day survived subhaloes as a function of the subhalo mass (lower axis). It follows the same trend as that of the progenitor population, with less massive subhaloes accreted earlier. As it can be clearly seen that most subhaloes of galactic haloes were accreted before redshift 1.7, whilst it is before redshift 0.9 for the Phoenix subhaloes. The result is consistent with the study of Boylan-Kolchin et al. (2009) who used the same definition of the accretion time to ours, while we extend the result to a lower subhalo mass. However this result is inconsistent with an earlier work of Gao et al. (2004) who found that most subhaloes are accreted later than $z = 0.5$. The discrepancy mainly lies in the definition of accretion time. In Gao et al. (2004), the accretion time of a subhalo is defined as the time it was lastly associated to an individual FOF halo. As we showed in the previous section that a quite large population of the 're-accreted' progenitor repeatedly passed through and was later re-accreted. In this work, the accretion time is defined at the time when a progenitor achieves its peak M_{200} , which is substantially earlier (Behroozi et al. 2014) than that of Gao et al. (2004).

4.2 The fate of accreted progenitors

After accretion, some progenitors will survive as subhaloes at present day, some will be completely destroyed by tidal field. Below we investigate the survival ability of progenitors. What is the fraction of them survive to present day? For the progenitor population accreted at a fixed redshift, what is the surviving fraction today? How much mass is retained in the survived subhaloes? It is also interesting to study whether the above physical quantities depends on the host halo mass.

We firstly consider below the survival number and mass fraction of progenitors who were accreted at two fixed redshifts, $z = 2$ and 4. Results are shown in Figure 4. The triangles connected by lines represent the survival number fraction of progenitors, while the squares connected by lines are for the retained mass fraction. The result for the Phoenix and the Aquarius haloes are distinguished with different colours. For massive progenitors with normalized mass $\log(M_{\text{prog}}/M_{200,z=0}) > 10^{-5}$ at $z = 2$, more than 80 percent of the entire progenitor population survives to the present day in Aquarius haloes. The fraction is 70 percent for Phoenix haloes. The survival number fraction is independent on the progenitor mass. The decline in the survival number fraction at the low mass end may be because of limited numerical resolution of our simulations. The retained mass fraction is quite different between two simulations. For progenitors of the Aquarius haloes, about 20 percent of its original mass is retained, a factor of 2 larger than those of Phoenix haloes. This suggests that tidal stripping process is more efficient in cluster than in galactic environments. Results for the progenitors accreted at $z = 4$ are qualitatively similar, albeit both the survival number and mass fraction is slightly lower because of earlier infall. Still about 60 percent of the accreted progenitors survive as entities in the tidal disruption process in Aquarius haloes. In Phoenix haloes the survival number fraction is much lower, at most 30 percent of progenitors survive through the tidal disruption. About 5 – 15 percent of their original mass is retained. The survival fraction and retain mass fraction might be slightly underestimated at massive end, since SUBFIND we used has trouble to identify subhalos near halo center (Muldrew, Pearce & Power 2011).

In Figure 5 we plot the survival number and mass fraction of all progenitors as a function of the progenitor mass during the entire assembly history of the Phoenix and the Aquarius haloes, where the median values of the Phoenix and the Aquarius haloes are shown. Different colours are used to distinguish different simulation sets, and different symbols are used to distinguish the number and mass fraction. As can be seen clearly that the survival number fraction of progenitors depend strongly on the progenitor mass for progenitors more massive than $1/100$ of their host halo mass, with more massive progenitors more easily destroyed. This is expected because dynamical friction effect is stronger for massive subhaloes, which assists the tidal stripping. Once progenitors mass are less than $1/100$ of their hosts, the survival number fraction becomes largely independent of the progenitor mass. During the entire assembly of Phoenix haloes, roughly 55 percent progenitors survive as subhaloes at present day, the survival fraction is only slightly lower for Aquarius haloes, which is about 50 percent. Presumably this results from earlier accretion of progenitor in galactic Aquarius haloes as we discussed above. Towards the low progenitor mass end, there is a drop in the survival number fraction, this is very likely caused by the numerical resolution of our simulations.

Square symbols connected with solid lines show the survival mass fraction of Phoenix and Aquarius haloes. In spite of the no-

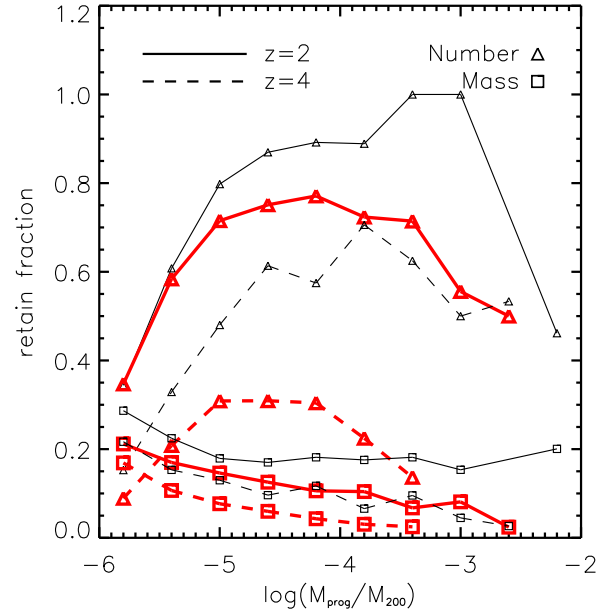


Figure 4. The survival number and mass fraction of progenitors accreted at redshift 4 and 2 as a function of the progenitors mass. The solid lines show result for redshift 2, and the dashed lines show result for 4. The number and mass fraction are distinguished with triangles and squares, respectively. Thick red curves show results for the Phoenix. Thin black curves are for the Aquarius.

ticeable difference in the survival number fraction between two simulation sets, the survival mass fraction of both simulations are quite similar. While most progenitors survive as entities at present day, about 90 percent of their original mass is striped. Although the accretion time of progenitors is more recent for Phoenix haloes, their survival mass fraction is very similar to that of the Aquarius, reflecting the fact that the tidal disruption process is stronger in more massive systems, consistent with what shows in the Figure 4.

4.3 Radial dependence of the retained mass of progenitors

A subhalo orbiting within its parent for a long time will have suffered significantly from the effects of dynamical friction and tidal stripping, so its orbit will have decayed by a larger factor than that of a recently accreted subhalo of similar current mass. This effect is expected to result in a correlation between the radial position of a subhalo and its accretion time. Gao et al. (2004) showed that there is indeed a tight relation between the retained mass fraction of progenitors and their radial position (see also Kravtsov, Gnedin & Klypin (2004)). The relation can be tested in future Galaxy-Galaxy lensing observations (Li et al. 2013, 2014). With 1000 times better resolution simulations, we revise the relation as follows.

In Figure 6 we plot the median values of the retained mass fraction of subhaloes against r/R_{200} for subhaloes of the Phoenix and the Aquarius haloes. In order to investigate whether the relation depends on the subhalo mass, we divide our subhalo population into two sub-samples, $10^{-6} < M_{\text{sub}}/M_h < 10^{-5}$ and $10^{-5} < M_{\text{sub}}/M_h$, respectively. The error bars represent full scatters of the Phoenix and the Aquarius suits. The strong radial dependence of retained mass fraction seems largely independent of the subhalo

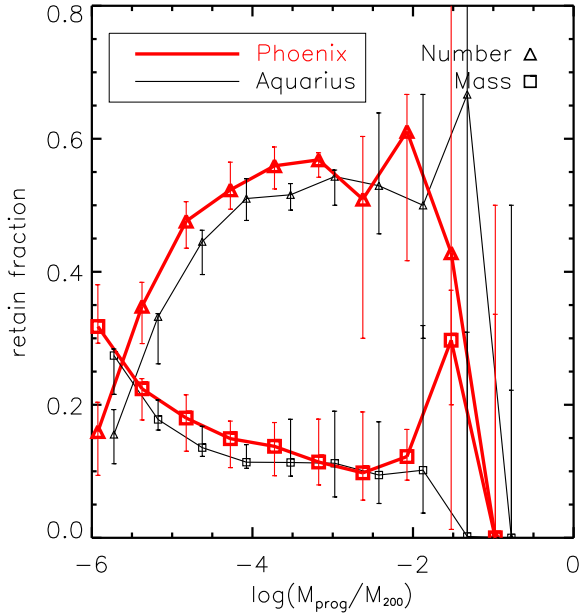


Figure 5. The survival number and mass fraction of all progenitors as a function of the progenitor mass. The triangles are the survived number fraction, the squares are the survived mass fraction. Thick red curves show results for the Phoenix. Thin black curves are for the Aquarius. The error bars show the full scatter of median.

mass. It weakly depends on the host halo mass, 4 percent difference in mass, but with large scatters. We provide a linear fit of a form:

$$f(r/R_{200}) = a \times r/R_{200} + b \quad (2)$$

For Phoenix haloes, $a = 0.4, b = 0.08$. For Aquarius haloes, $a = 0.38, b = 0.06$. The fits are shown as pink (Phoenix) or gray (Aquarius) dashed lines.

5 CONCLUSION

We take advantage of two sets of ultra high resolution N -body simulations from the Phoenix and the Aquarius Project to explore systematics in the assembly history of subhaloes in dark matter haloes of different masses. The Phoenix and the Aquarius simulations have the same effective mass and force resolution. This allows us to make fair comparison of the evolution of subhaloes and their progenitors between cluster and galaxy sized dark matter haloes.

We have adopt a more detailed tracking procedure to follow the evolution of progenitors. By exercising this, we find that a quite large population of progenitors of a final host halo passed through and were later re-accreted to the main progenitor more than once. The averaged fraction of the 're-accreted' progenitors vary with the halo mass, which is about 60 percent for the Aquarius haloes and 40 percent for the Phoenix haloes. There is also a substantial 'ejected' halo population accreted to its host in the past but being in isolation at present day. We find that the abundance of progenitors which build up present day subhalo population systematically depends on the host halo mass, in contrast to previous studies. The amplitude of the un-evolved subhalo mass function depends systematically on the host halo mass, the cluster sized haloes on average have at least 20 percent more progenitors than that of galactic counterparts.

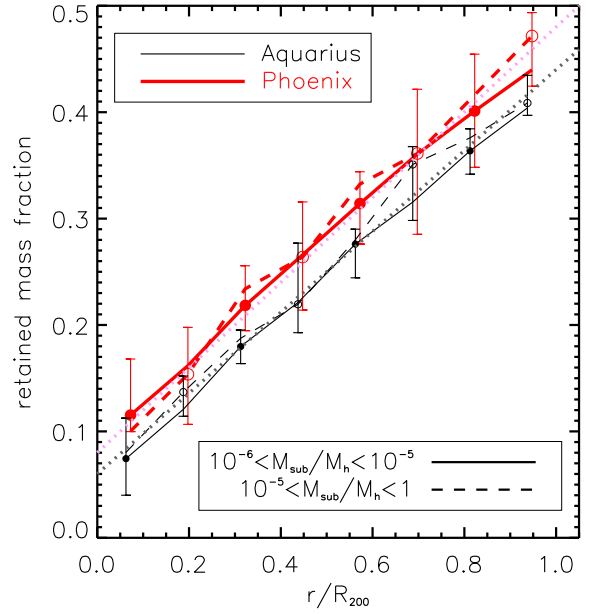


Figure 6. The ratio between the present subhalo mass and its original mass at accretion as a function of centric distance. The medial value of the Phoenix and Aquarius are shown. The solid lines are the results of subhaloes with present mass $M_{sub}/M_h < 10^{-5}$. The dashed lines are the results of subhaloes with present mass $M_{sub}/M_h > 10^{-5}$. Thick red curves show results for the Phoenix and thin black curves are for the Aquarius. The blue dotted lines show a linear fits to the radial dependence.

The accretion time of progenitors depend on the host halo mass as well as the progenitor mass. Typically most progenitors of the galactic haloes were accreted before a redshift $z = 5$, while the accretion time for progenitors of clusters is about $z = 3$. Less massive progenitors are accreted earlier than more massive ones. At the fixed progenitor mass, the survival number fraction of progenitors does not depend on the host halo mass, while the retained mass fraction correlates with the host halo mass. Tidal stripping is more efficient in cluster environment than in that of galaxy. For the progenitor population as a whole, 55 percent of them are able to survive as entities at present day for galactic haloes, the survival number fraction for clusters is only slightly lower, which is 50 percent. Nevertheless, the survived subhaloes roughly retain 10 percent of their original mass, independent on the host halo mass. The evolution of subhaloes leads to a radial dependence of the retained mass fraction. The relation seems largely independent of the host halo mass as well as the subhalo mass, we provide a simple fit to it.

These systematics between the assembly of subhaloes in cluster sized and galactic haloes should account for similarities and differences in the host mass dependence of subhalo population seen in N -body Cosmological simulations.

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